DUSEL Cryo Tank and Plant		Failure Mode and Effects Review			April 12 201
System	**Component**	**Failure Scenario**	**Consequence**	**Protection**	**Action/ Note**
Membrane Structure	Membrane	Leakage through defect in construction	Loss of liquid Ar to insulation. Insulation effectiveness reduced. Ar leak to purge / vent system	Conventional detailing for cryogenic conditions from LNG experience. Construction of membrane includes leak tightness test as standard.	
Membrane Structure	Membrane	Leakage through contact with TPC – abrasion, corrosion	Loss of liquid Ar to insulation. Insulation effectiveness reduced. Ar leak to purge vent system	Designed interface between membrane & TPC to control contact forces and return of purified Ar to cryostat at low level to reduce turbulence and vibration	
Membrane Structure	Membrane	Leakage at pipe penetration of membrane	Loss of vapor Ar to cavern above cryostat; Possible entry of air to cryostat if internal pressure is below ambient	Conventional detailing for cryogenic conditions from LNG experience. Construction of membrane includes leak tightness test as standard.	

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Membrane Structure	Pump well seal	Loss of Ar to cavern during pump extraction/ replacement	Uncontrolled boil-off of Ar to cavern	Pump well has isolation valve at foot so well is closed off from main tank when pump is removed. Open top of well allows heavier-than-air gas to spill while pump is being handled.	Advisable to detail worksite so that maintainers are as far as possible above cryostat roof and open top of well. Provide breathing apparatus in emergency equipment. Ensure procedures in place to control personnel access within cavern.
Membrane Structure	Pump well seal	Contaminants on pump when it is returned to cryostat after maintenance/ repair	Contamination of Ar	Pump can be run preferentially to extract contaminated Ar from well before it percolates into main volume	Note for operating procedure
Modular Structure	Inner structure	Leakage through defect in construction	Loss of liquid Ar to insulation. Insulation effectiveness reduced. Ar leak to purge vent system	Convention detailing for cryogenic conditions from LNG experience. Construction of inner tank includes leak tightness test as standard.	
Modular Structure	Inner structure	Leakage through contact with TPC – abrasion, corrosion	Loss of liquid Ar to insulation. Insulation effectiveness reduced. Ar leak to purge vent system	Design of modular structure and internal restraints integrated with design of TPC	

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Modular Structure	Inner structure	Leakage at pipe penetration of containment	Loss of vapor Ar to cavern above cryostat; Possible entry of air to cryostat if internal pressure is below ambient	Conventional detailing for cryogenic conditions from LNG experience. Construction of inner tank includes leak tightness test as standard.	
Modular Structure	Pump well seal	Loss of Ar to cavern during pump extraction/ replacement	Uncontrolled boil-off of Ar to cavern	As above for membrane structure	As above for membrane structure
Modular Structure	Pump well seal	Contaminants on pump when it is returned to cryostat after maintenance/ repair	Contamination of Ar	As above for membrane structure	As above for membrane structure
Structures	Containment	High pressure in cryostat fails roof structure	Uncontrolled release of Ar	Pressure relief valves to surface	
Structures	Containment	Low pressure in cryostat fails roof structure	Uncontrolled release of Ar	Continuous boil-off means that gas space will tend to pressurize. Pressure control valve in boil-off stream controls pressure in cryostat and flow through recondenser.	
Pipework	Vapor pipework to recondenser	Leakage	Release of Ar vapor to cavern	Double-walled vacuum insulated pipework	Confirm detection in cavern based on thermal parameters

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Pipework	Vapor pipework to recondenser	Leakage	Contamination of Ar	Vapor pipework is expected to be pressurized above ambient by boil-off. Double-walled vacuum insulated pipework. Recondensed Ar returned to cryostat via purifier	
Pipework	Vapor pipework to relief vent	Leakage	Release of Ar vapor to cavern	Double-walled vacuum insulated pipework Emergency provision; no gas under normal operation	Confirm detection in cavern based on thermal parameters
Pipework	Vapor pipework to relief vent	Failure of pressure relief valve to open, or of blower to lift vapor to surface (for 4,850' case)	Release of Ar vapor to cavern	Emergency provision; no gas under normal operation	
Pipework	Vapor pipework to relief vent	Pressure relief valve opens and relief vent pipe rapidly cools from ambient to vapor temperature	Rapid contraction of pipe, longitudinal movement		Requires attention in support/ restraint details
Pipework	Vapor pipework	Boil-off released when system is breached in order to repair/ replace defective or damaged pipework	Release of Ar vapor to cavern	Conventional isolation valves in pipework. All pipework can be isolated at cryostat roof so the bulk of the Ar inventory can be held in the cryostat if any or all of the systems outside the cryostat need to be worked on.	

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Insulation purge	Blower	Leakage from blower casing (eg seals)	Release of Ar vapor to cavern	Use of plant appropriate to L.Ar	To be addressed in choice & detailing of blower
Insulation purge	Blower	Leakage into blower casing (eg seals)	Contamination of Ar	Use of plant appropriate to L.Ar	To be addressed in choice & detailing of blower
Insulation purge	Blower	Fail to operate	No purge flow through insulation. Not critical to operation	Use of plant appropriate to L.Ar	
Insulation purge	Containment	Contaminating purge gas enters cryostat through defect in membrane/ inner tank	Contamination of Ar	Purge with Ar boil-off; most of cryostat liquid above purge gas pressure	
Insulation purge	Containment	Contaminants picked up in insulation	Contamination of Ar	Purge with Ar boil-off passed through recondenser and purifier before return to cryostat	
Pipework	Liquid pipework between recondenser, purifier & cryostat	Leakage	Release of Ar vapor to cavern	Double-walled vacuum insulated pipework	Confirm detection in cavern based on thermal parameters
Pipework	Liquid pipework between recondenser, purifier & cryostat	Leakage of air into pipework	Contamination of Ar	Double-walled vacuum insulated pipework; pressure inside is above ambient	

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Pipework	Liquid pipework	Liquid released when system is breached in order to repair/ replace defective or damaged pipework	Release of Ar vapor to cavern	Conventional isolation valves in pipework. All pipework can be isolated at cryostat roof so the bulk of the Ar inventory can be held in the cryostat if any or all of the systems outside the cryostat need to be worked on.	Drain and vent tappings should be included in detailed design
Recondenser	Containment	Outer wall of recondenser breached	Release of Ar or N_2 to cavern	Recondenser is double-walled with sealed vacuum insulation	
Recondenser	Containment	Heat exchanger tube defect	Leak of N_2 into Ar stream	Quality control in manufacture. N_2 will be found and extracted in purifier. Monitoring purifier will indicate if N_2 leak is taking place	100% redundancy means a recondenser can be taken down for inspection and repair
Recondenser	Containment	Heat exchanger tube defect	Leak of Ar into N_2 stream	Quality control in manufacture. N_2 should be liquid around the Ar vapor tubes, therefore at higher pressure. If Ar does leak it will liquefy and remain in the condenser	
Refrigeration System	Pipework	Leakage	Release of N_2 to cavern	Double-walled vacuum insulated pipework	Confirm detection in cavern based on thermal parameters

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Refrigeration System	Pipework	Leakage of air into pipework	Contamination of N_2	Double-walled vacuum insulated pipework; pressure inside is above ambient	
Refrigeration System	Refrigeration & circulation pumping	Mechanical fault	Liquid N_2 not available to recondense boil-off	100% redundancy in all mechanical plant	
Recondensed Ar	Pump	Mechanical fault	Ar boil-off / recondense stream shut down	100% redundancy in all mechanical plant	
Cryostat pressure relief	4,850' cavern system blower	Failure of blower on demand	Ar released to cavern	Rare double failure of pressure control and blower	Risk managed by maintenance and test regime of blower